

*Asociación Argentina de Astronomía*

*BAAA, Vol. 48, 2005*

*E.M. Arnal, A. Brunini, J.J. Clariá, J.C. Forte, D.A. Gómez, D. García Lambas,  
Z. López García, Stella M. Malaroda, & G.E. Romero, eds.*

## COMUNICACIÓN DE TRABAJO – CONTRIBUTED PAPER

### Impact of Supernova Explosions on Galaxy Formation

Cecilia Scannapieco

*Instituto de Astronomía y Física del Espacio, Buenos Aires, Argentina,  
cecilia@iafe.uba.ar*

Patricia B. Tissera

*Instituto de Astronomía y Física del Espacio, Buenos Aires, Argentina,  
patricia@iafe.uba.ar*

Simon D.M. White

*Max-Planck Institute for Astrophysics, Garching, Germany,  
swhite@mpa-garching.mpg.de*

Volker Springel

*Max-Planck Institute for Astrophysics, Garching, Germany,  
volker@mpa-garching.mpg.de*

**Abstract.** We study the effects of Supernova (SN) feedback on the formation of disc galaxies. For that purpose we run simulations using the extended version of the code GADGET-2 which includes a treatment of chemical and energy feedback by SN explosions. We found that our model succeeds in setting a self-regulated star formation process since an important fraction of the cold gas from the center of the haloes is efficiently heated up and transported outwards. The impact of SN feedback on galactic systems is also found to depend on virial mass: smaller systems are more strongly affected with star formation histories in which several starbursts can develop. Our implementation of SN feedback is also successful in producing violent outflows of chemical enriched material.

**Resumen.** En este trabajo se estudia el impacto de explosiones de Supernova (SN) en la formación de galaxias de disco. Para ello se utilizan simulaciones numéricas realizadas con una versión del código GADGET-2 que incluye los efectos de enriquecimiento químico e inyección de energía debido a explosiones de SN. Este modelo es capaz de generar un mecanismo auto-regulado de formación estelar, como resultado del calentamiento eficiente del gas en el centro de los sistemas y su transporte hacia el halo. En nuestro modelo, el impacto de las explosiones de SN en sistemas galácticos depende de la masa virial de los mismos: los más pequeños son afectados más fuertemente pudiendo presentar varios brotes de formación estelar. Nuestro modelo es también capaz de producir fuertes flujos de gas hacia las regiones externas de las galaxias, los

cuales transportan una importante fracción de metales hacia el medio intergaláctico.

## 1. Introduction

Supernova explosions are thought to play a fundamental role in the evolution of galaxies. Through the ejection of metals and energy into the interstellar medium, they significantly affect the gas collapse, the star formation activity and the chemical patterns. As a consequence, SN feedback would be able to set a self-regulated mechanism for the star formation activity and the enrichment of the Universe. Moreover, SN driven outflows are believed to be responsible for the presence of metals detected in the intergalactic medium (e.g. Tytler et al. 1995; Songaila & Cowie 1996).

In the context of numerical simulations, the treatment of SN feedback has found severe complications. Several works have developed models of different complexity to treat SN feedback in Smoothed Particle Hydrodynamics (SPH; Gingold & Monaghan 1977; Lucy 1977) codes (e.g. Katz & Gunn 1991; Navarro & White 1993; Metzler & Evrard 1994; Marri & White 2003; Springel & Hernquist 2003), finding different levels of success.

## 2. Numerical Models

In this study, we analyse simulations of isolated disc galaxies of different virial masses from idealized initial conditions. The initial conditions correspond to spherical distributions of superposed gaseous and dark matter particles, perturbed to give rise to a density profile of the form  $\rho(r) \propto r^{-1}$ . The spheres are initially in solid body rotation with a spin parameter of  $\lambda \approx 0.1$ . We have used an initial number of 9000 both gaseous and dark matter particles for all masses. The simulations were performed with the extended version of the Tree-PM SPH code GADGET-2 (Springel & Hernquist 2002) which includes a treatment of chemical enrichment and energy feedback by Supernova (Scannapieco et al. 2005a,b,c). The model is tight to a multiphase scheme which allows a better description of diffuse gas in the context of the SPH technique. The interested reader is referred to Scannapieco et al. 2005a,b for details on the numerical scheme. All experiments presented in this study include chemical enrichment and metal-dependent cooling, and they all have been run in the context of the multiphase treatment for the gas component.

It is relevant to this study to mention that the energy feedback model has only one free input parameter. Within the model, we define for each star particle with associated SN explosions two gaseous phases in the following manner: a *cold* phase defined as the gas with  $T < 2T_*$  and  $\rho > 0.1\rho_*$  ( $T_* = 4 \times 10^4$  K,  $\rho_* = 7 \times 10^{-26}$  g cm $^{-3}$ ) and a *hot* phase formed by the remaining gas. The energy released in the explosions, as well as the metal content, are distributed into the cold and hot phases: the cold phase receives a fraction  $\epsilon_c$  while the hot phase gets the remaining  $\epsilon_h = 1 - \epsilon_c$ . Hence, the parameter  $\epsilon_c$  (or  $\epsilon_h$  equivalently) is the only free parameter to assume. Note that the value of  $\epsilon_c$  is related to the power of the feedback. However, we note that the effects of varying its value are

not completely linear, owing to the non trivial interplay among energy release, heating and cooling (see Scannapieco et al. 2005b).

### 3. Results

We analyse here results for isolated disc galaxy simulations, in the virial mass range  $10^{9.5} - 10^{12} h^{-1} M_{\odot}$ . In Fig. 1 we show the evolution of the star formation rate for tests of  $10^{12} h^{-1} M_{\odot}$  (upper panel),  $10^{10.5} h^{-1} M_{\odot}$  (middle panel) and  $10^{9.5} h^{-1} M_{\odot}$  systems (lower panel). We have plotted the curves for experiments performed without including energy feedback (solid lines) and including feedback with an input parameter of  $\epsilon_c = 0.5$  (dashed lines). These trends indicate that the inclusion of the model of SN energy feedback succeeds in regulating the star formation activity in galaxies. This is the result of the effects of the injection of energy into the interstellar gas: when SNe explosions take place, the gas is efficiently heated up and accelerated outwards. As a result, the cold gas density from which stars are formed decreases and the star formation rate is reduced. Note also that lower mass systems are more strongly affected, as expected since their potential wells are less efficient in retaining baryons (Larson 1974).

As it was mentioned before, SN feedback is responsible of heating up the gas in star forming regions and, consequently, of generating important outflows of material. Since these outflows originate in the center of the systems where the gas is highly enriched with metals, they can transport an important fraction of the chemical elements into the haloes and even beyond. This could in principle explain the observed presence of metals in the intergalactic medium. As an example, we show in Fig. 2 the edge-on projected gas metallicity distribution for our test of  $10^{12} h^{-1} M_{\odot}$  virial mass system just after the starburst. From this figure we can see that our model is able to enrich the regions outside the centre of galaxies. Also note that the generated outflows are mostly perpendicular to the disc plane.

### 4. Conclusions

We have presented results of the effects of SN feedback on the evolution of isolated disc galaxies of different mass, by using an extended version of the code GADGET-2 which includes a treatment of chemical and energy feedback by Supernova. We have shown that the model succeeds in generating a self-regulated star formation process, as a consequence of the triggering of strong outflows of material.

We found that the impact of SN feedback on galaxy formation depends on virial mass. Smaller systems are more strongly affected since they have shallower potential wells and hence are less efficient in retaining baryons. In particular, we found that the star formation rates of small systems such as dwarf galaxies can show a series of starbursts, in consistency with recent observational findings (Kauffmann et al. 2003; Tolstoy et al. 2003).

In our model, galactic outflows transport an important fraction of the metal content from the centre to the outskirts of galaxies. This is of crucial importance since it is observed that the intergalactic medium is contaminated with heavy

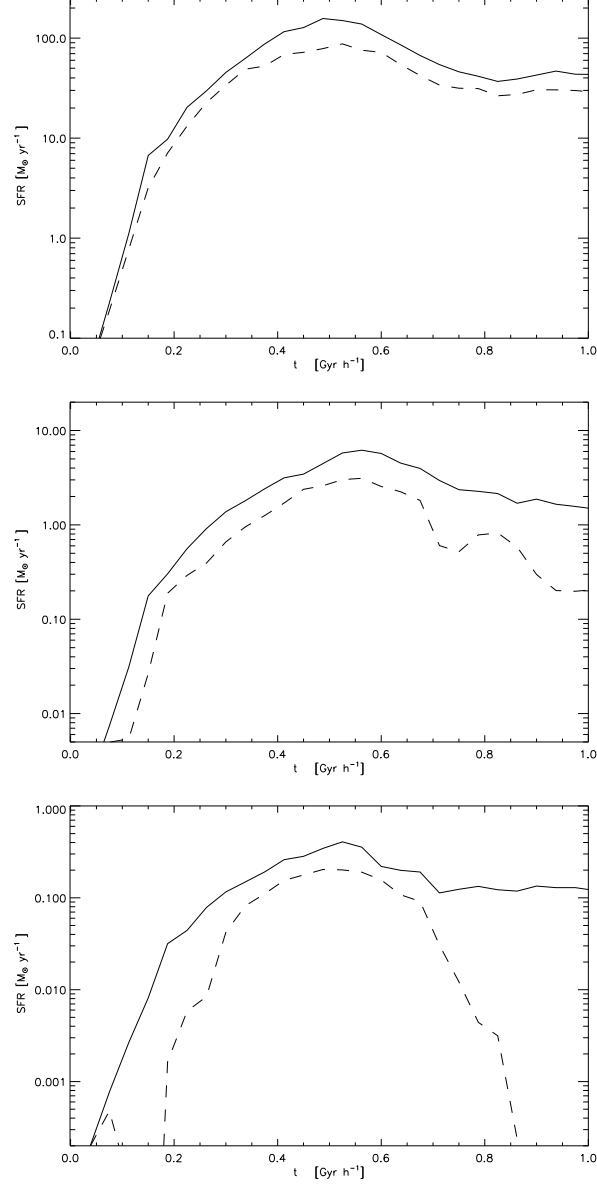


Figure 1. Evolution of the star formation rates for our tests of isolated rotating spheres with virial masses of  $10^{12} h^{-1} M_{\odot}$  (upper panel),  $10^{10.5} h^{-1} M_{\odot}$  (middle panel) and  $10^{9.5} h^{-1} M_{\odot}$  (lower panel). We have plotted the curves for experiments performed without including energy feedback (solid lines) and including feedback with an input parameter of  $\epsilon_c = 0.5$  (dashed lines).

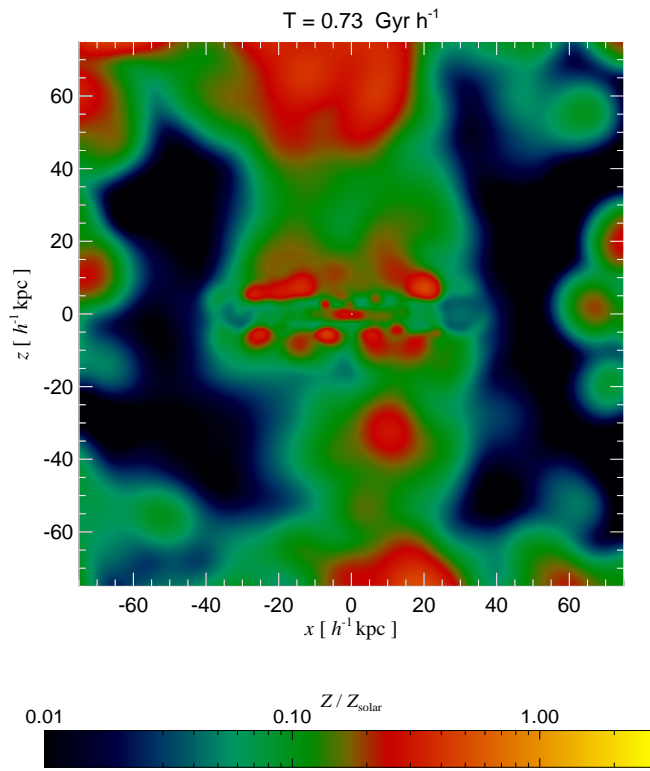


Figure 2. Edge-on gaseous metallicity distribution for our  $10^{12} h^{-1} M_{\odot}$  virial mass system run including the feedback model with an input parameter of  $\epsilon_c = 0.5$  (dashed lines), after  $0.75 \text{ Gyr } h^{-1}$  of evolution. The metallicity scale is also shown.

metals. SN driven outflows such as those generated by our model constitute a natural explanation for this observational result.

**Acknowledgments.** This work was partially supported by the European Union's ALFA-II program, through LENAC, the Latin American European Network for Astrophysics and Cosmology. Simulations were run on Ingeld and HOPE PC-clusters at Institute for Astronomy and Space Physics. We acknowledge support from Consejo Nacional de Investigaciones Científicas y Técnicas, Agencia de Promoción de Ciencia y Tecnología, Fundación Antorchas and Secretaría de Ciencia y Técnica de la Universidad Nacional de Córdoba. The authors thank the Aspen Center for Physics where part of the discussions of this work took place.

## References

- Gingold R.A., Monaghan J.J., 1977, MNRAS, 181, 375  
 Katz N., Gunn J.E., 1991, ApJ, 377, 365  
 Kauffmann G., et al., 2003, MNRAS, 341, 54  
 Larson R.B., 1974, MNRAS, 169, 229  
 Lucy L.B., 1977, ApJ, 82, 1013  
 Marri S., White S.D.M., 2003, MNRAS, 345, 561  
 Metzler C., Evrard A., 1994, ApJ, 437, 564  
 Navarro J.F., White S.D.M., 1993, MNRAS, 265, 271  
 Scannapieco C., Tissera P.B., White S.D.M., Springel V., 2005a, MNRAS, in press (astro-ph/0505440)  
 Scannapieco C., Tissera P.B., White S.D.M., Springel V., 2005b, in preparation  
 Scannapieco C., Tissera P.B., White S.D.M., Springel V., 2005c, *Proceedings for the Vth Marseille International Cosmology Conference: The Fabulous Destiny of Galaxies* (astro-ph/0509440)  
 Songaila A., Cowie L.L., 1996, ApJ, 112, 335  
 Springel V., Hernquist L., 2002, MNRAS, 333, 649  
 Springel V., Hernquist L., 2003, MNRAS, 339, 289  
 Tolstoy E., Venn K.A., Shetrone M., Primas F., Hill V., Kaufer A., Szeifert T., 2003, ApJ, 125, 707  
 Tytler D., Fan X.-M., Burles S., Cottrell L., Davis C., Kirkman D., Zuo L., 1995, *QSO Absorption Lines, Proceedings of the ESO Workshop Held at Garching, Germany, 21 - 24 November 1994*, edited by Georges Meylan. Springer-Verlag Berlin Heidelberg New York.